MichiganEngineering

Crack Opening Displacement Behavior in Ceramic Matrix Composites

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41st Annual Conference on Composites, Materials, and Structures

Motivation

- Experimental Data for Modeling
  - Robust CMC life prediction capabilities require experimental data for inputs and validation
  - Crack opening measurements to support environmental degradation modeling
- Understanding Crack Propagation
  - How do cracks interact with the microstructure?
  - In what way do microstructural features drive crack path?

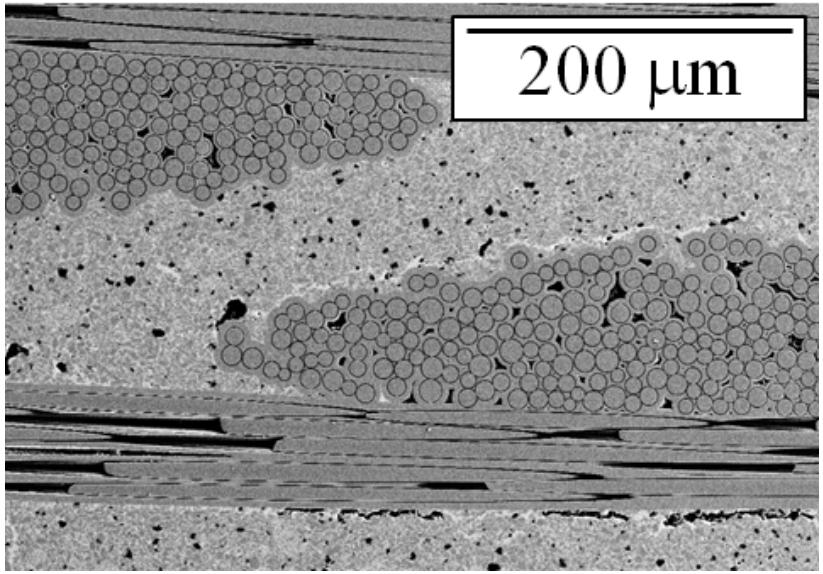
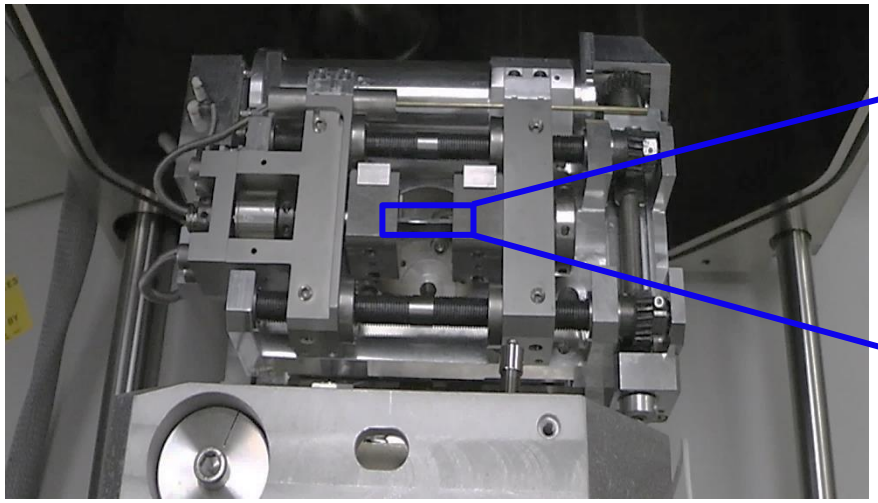
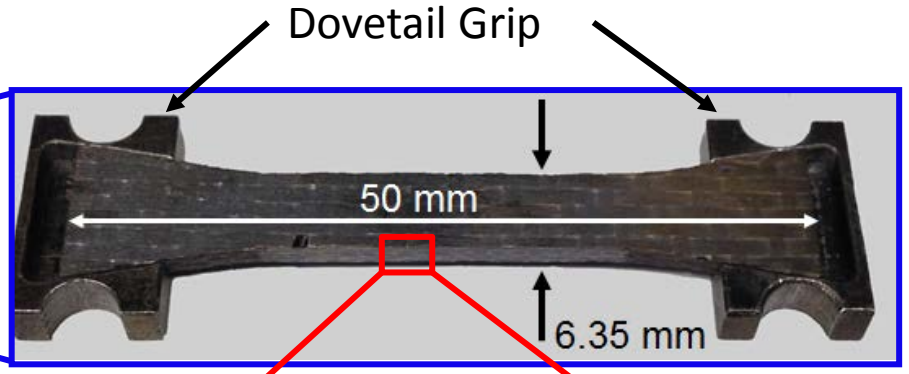


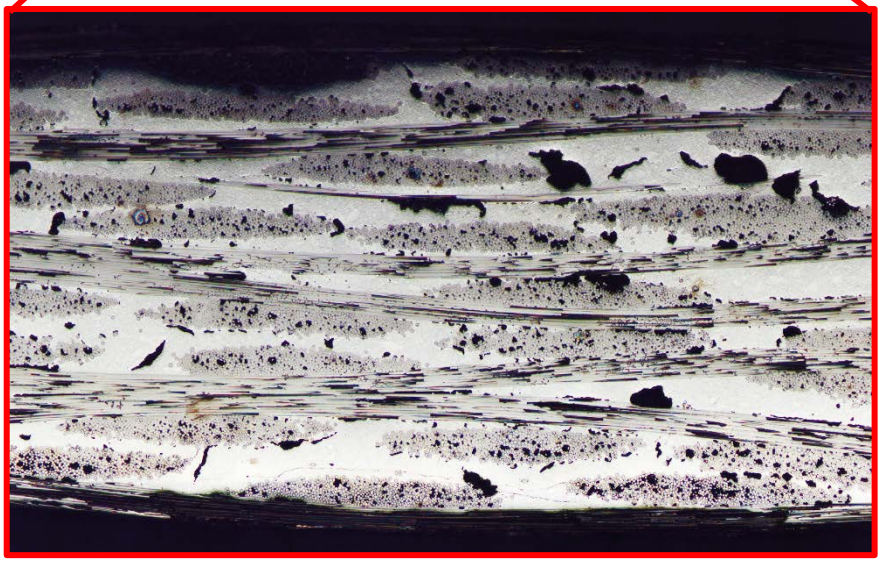
Image Courtesy of NASA GRC

- Sylramic fiber reinforced, slurry cast MI SiC/SiC
- CODs predicted to be very - small
- Observe cracking in-situ with small tensile loading stage in SEM

Loading and Imaging Configuration



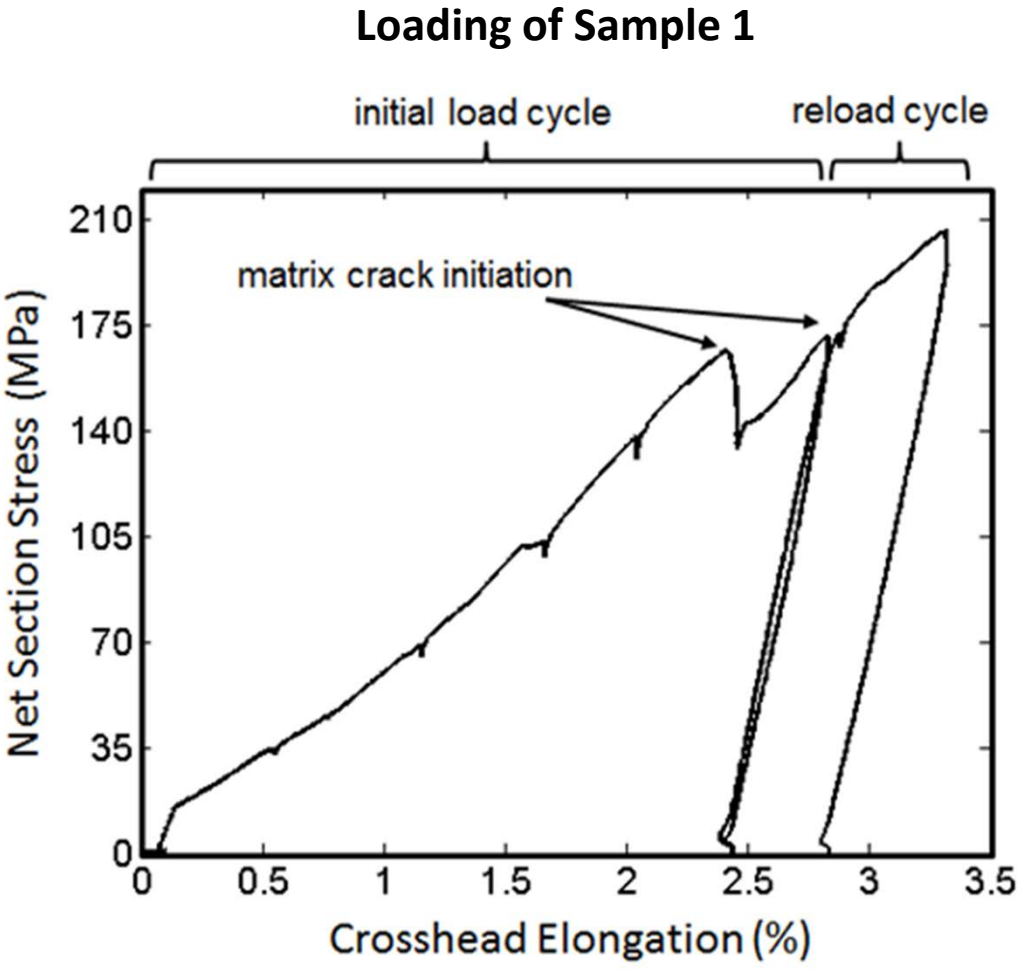




- Sample can be configured to observe sample edge or face
- Loading performed in displacement control

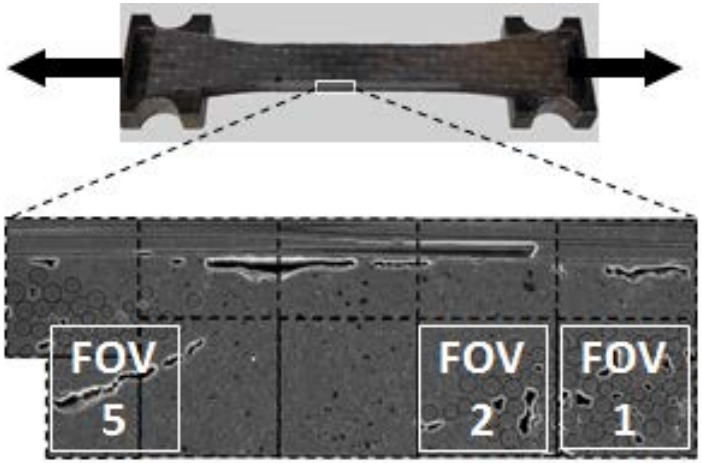
Basic Procedure

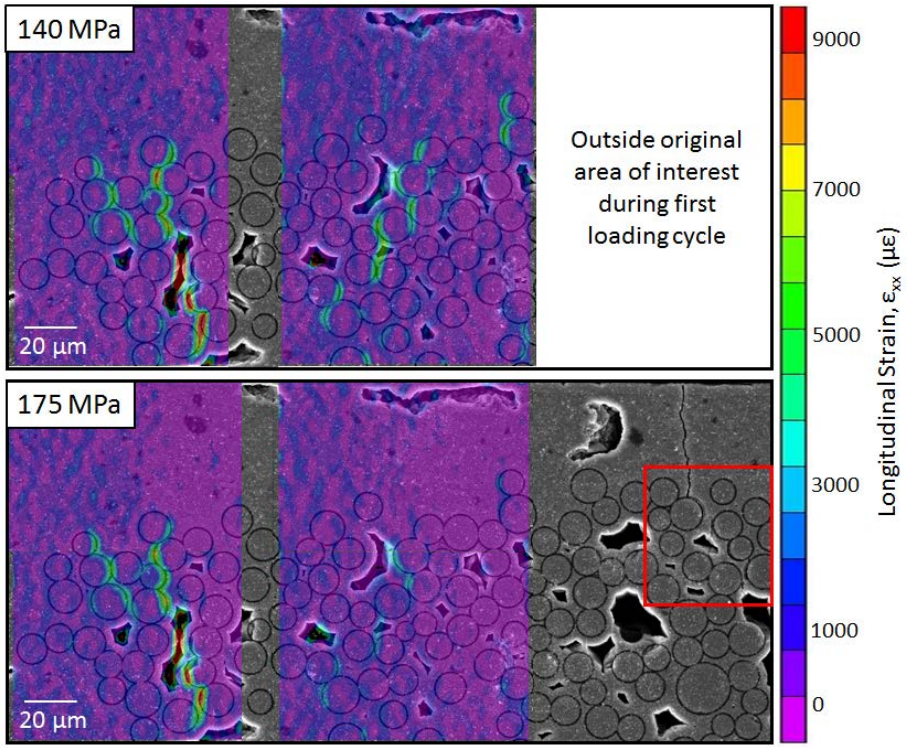
- Increment load ~35 MPa per step
- Loading paused at each stress increment to capture SEM images
- Images captured after load relaxed
- Images captured at multiple magnifications to document crack quantity, density, and location of COD measurements
- Two samples tested
  - Sample 1 results detailed in 2016 – reviewed here
  - Sample 2 preliminary results presented here



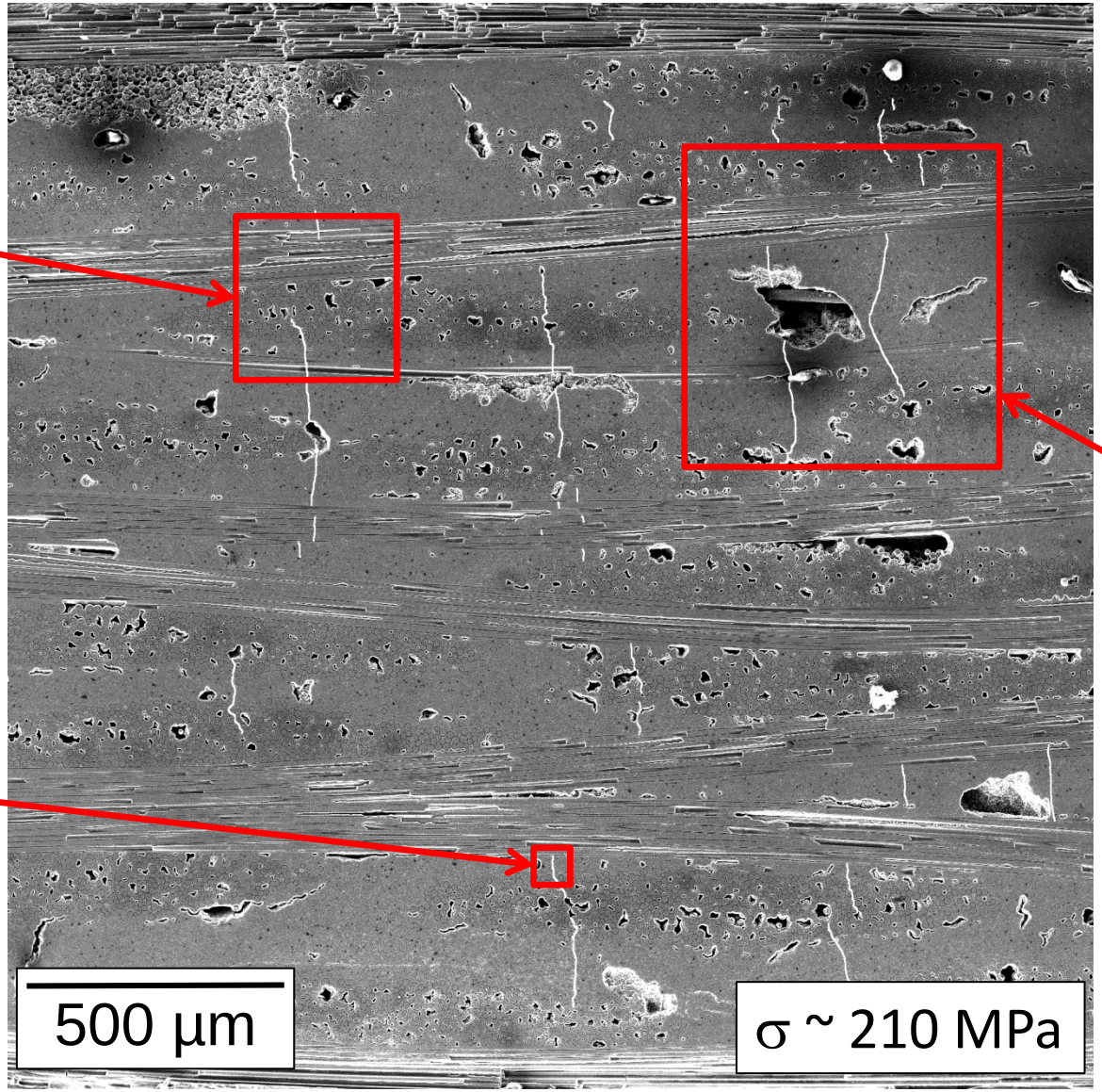
Initial Study : SEM-DIC and COD Measurements

- SEM-DIC analysis performed over initial AOI with 10 FOVs
- No matrix cracks in initial AOI - crack just to the right of AOI
- Sample unloaded to image crack area while unloaded, then reloaded to above matrix cracking stress (second loading)
- Limited COD data from SEM-DIC due to small sampling areas
- Sample reloaded (third loading) to measure COD at additional locations

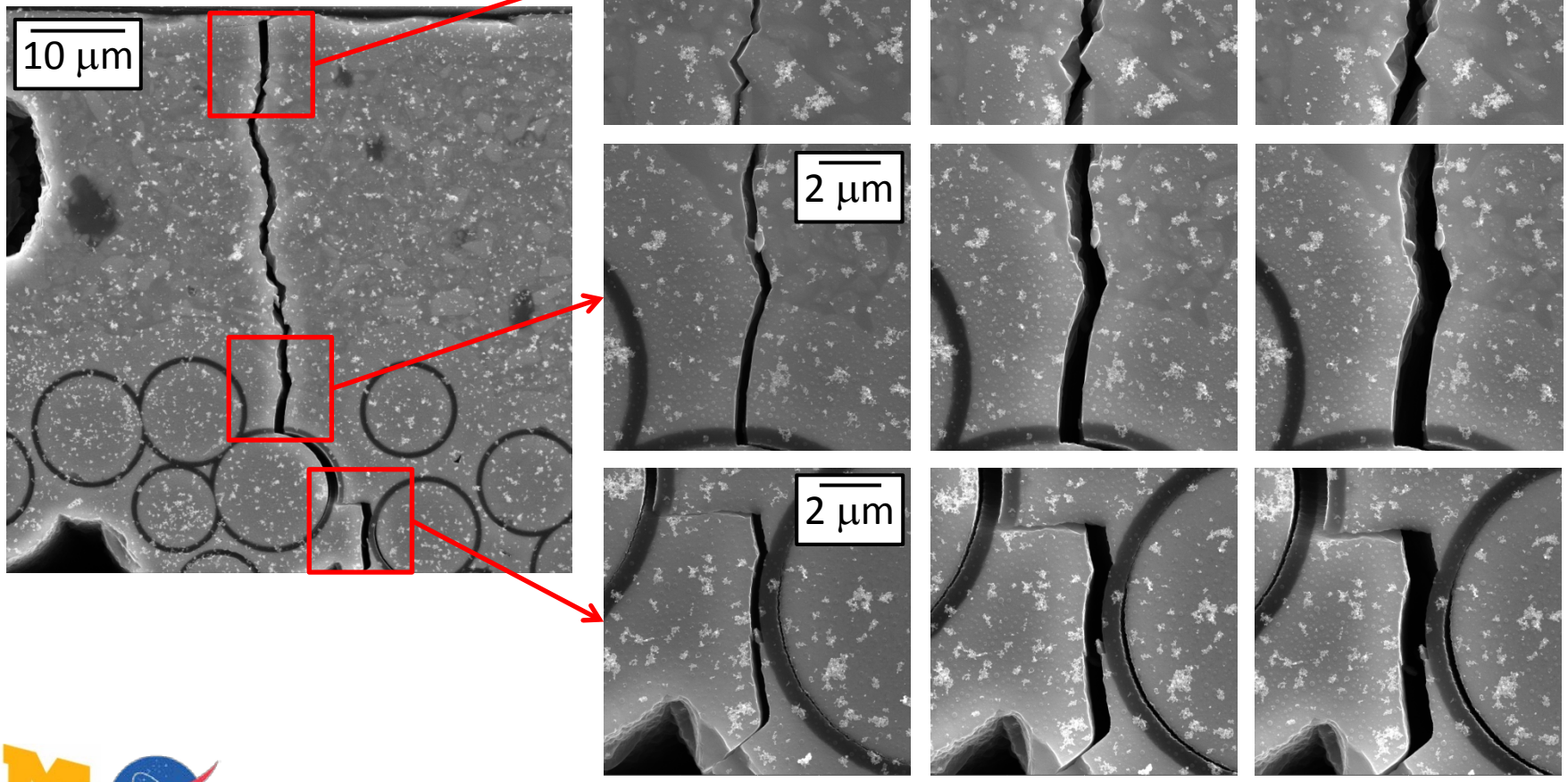


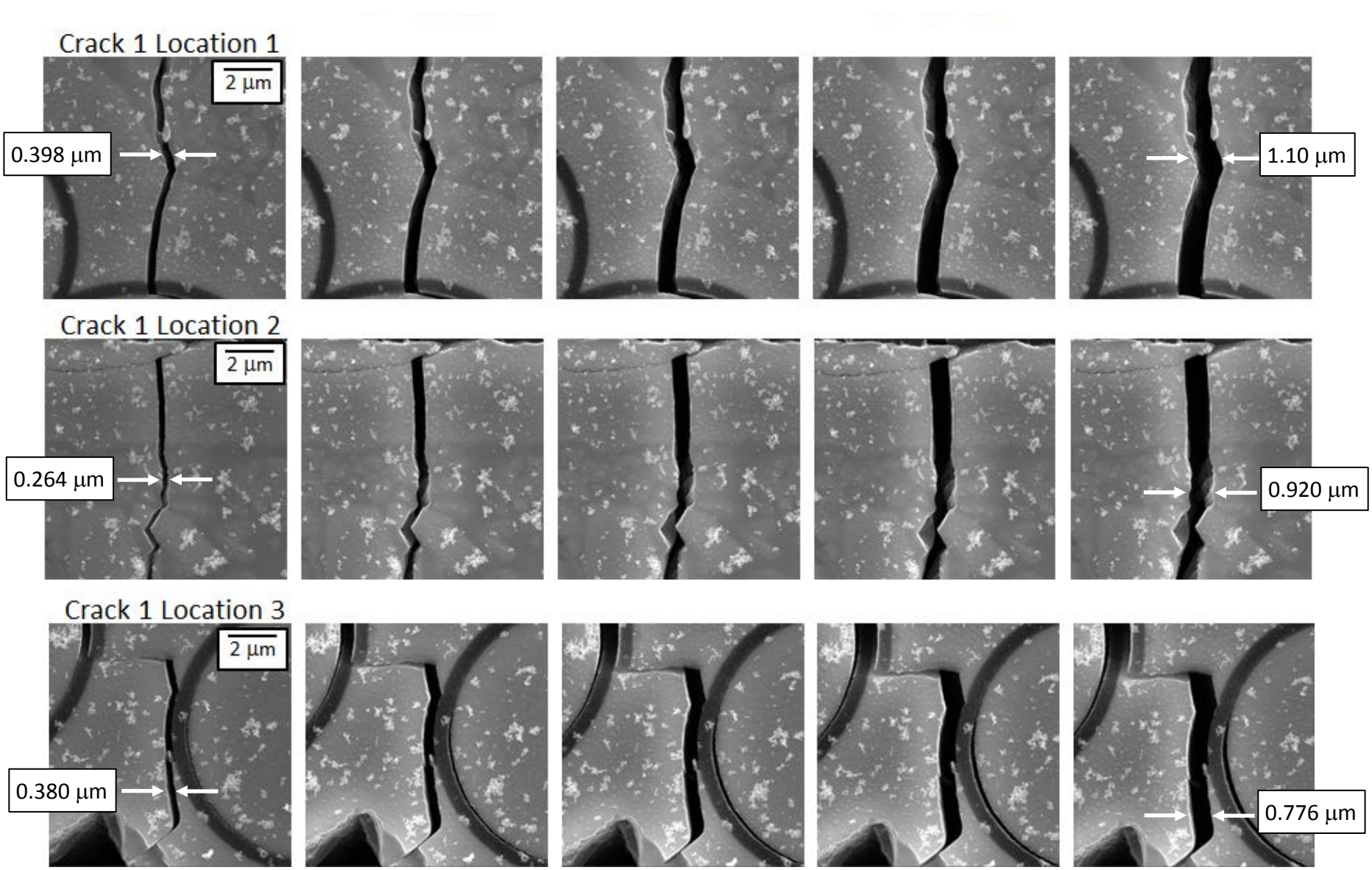


Sample 1 - Cracks observed across the cross-section

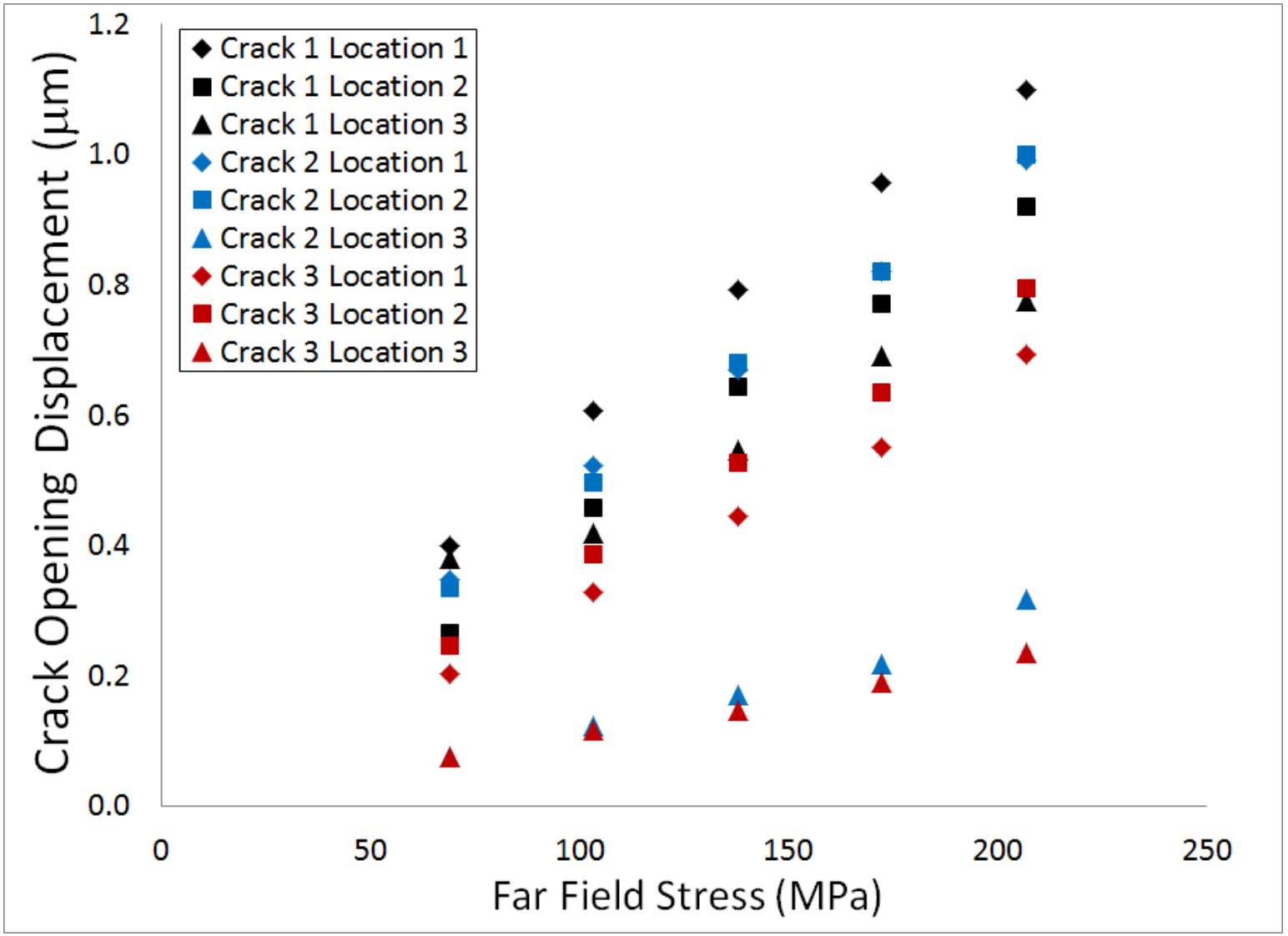


Crack 1 Images Captured on Third Loading




σ ~ 70 MPa
σ ~ 105 MPa
σ ~ 140 MPa
σ ~ 175 MPa
σ ~ 210 MPa
Crack 1 Location 1
2 µm
0.398 µm
1.10 µm
Crack 1 Location 2
2 µm
0.264 µm
0.920 µm
Crack 1 Location 3
2 µm
0.380 µm
0.776 µm

Matrix Crack Opening Exhibited Variability



Conclusions and Questions From Sample 1

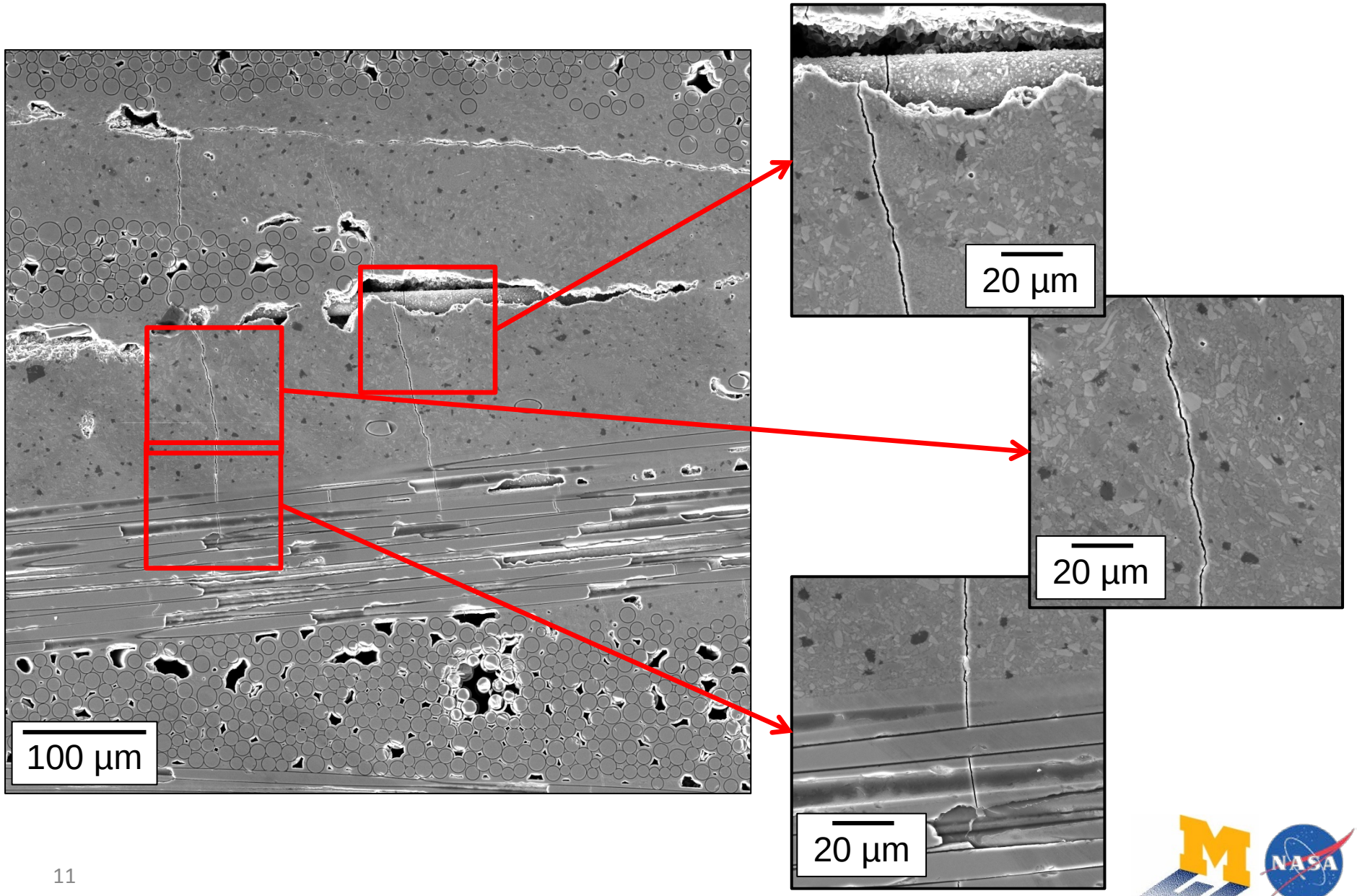
Conclusions

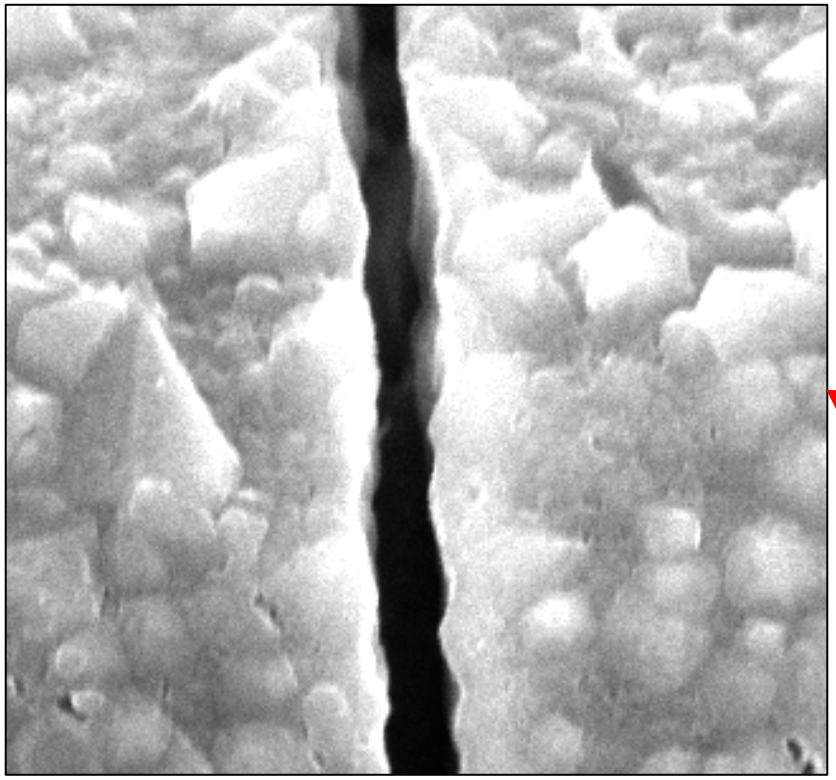
- Fiber/matrix interface damage at far field stresses as low as 35 MPa
- Strain relaxation observed adjacent to matrix cracks after initial matrix cracking
- Crack opening displacements varied from 0.2 to 1.5 μm at a far field stress of 210 MPa

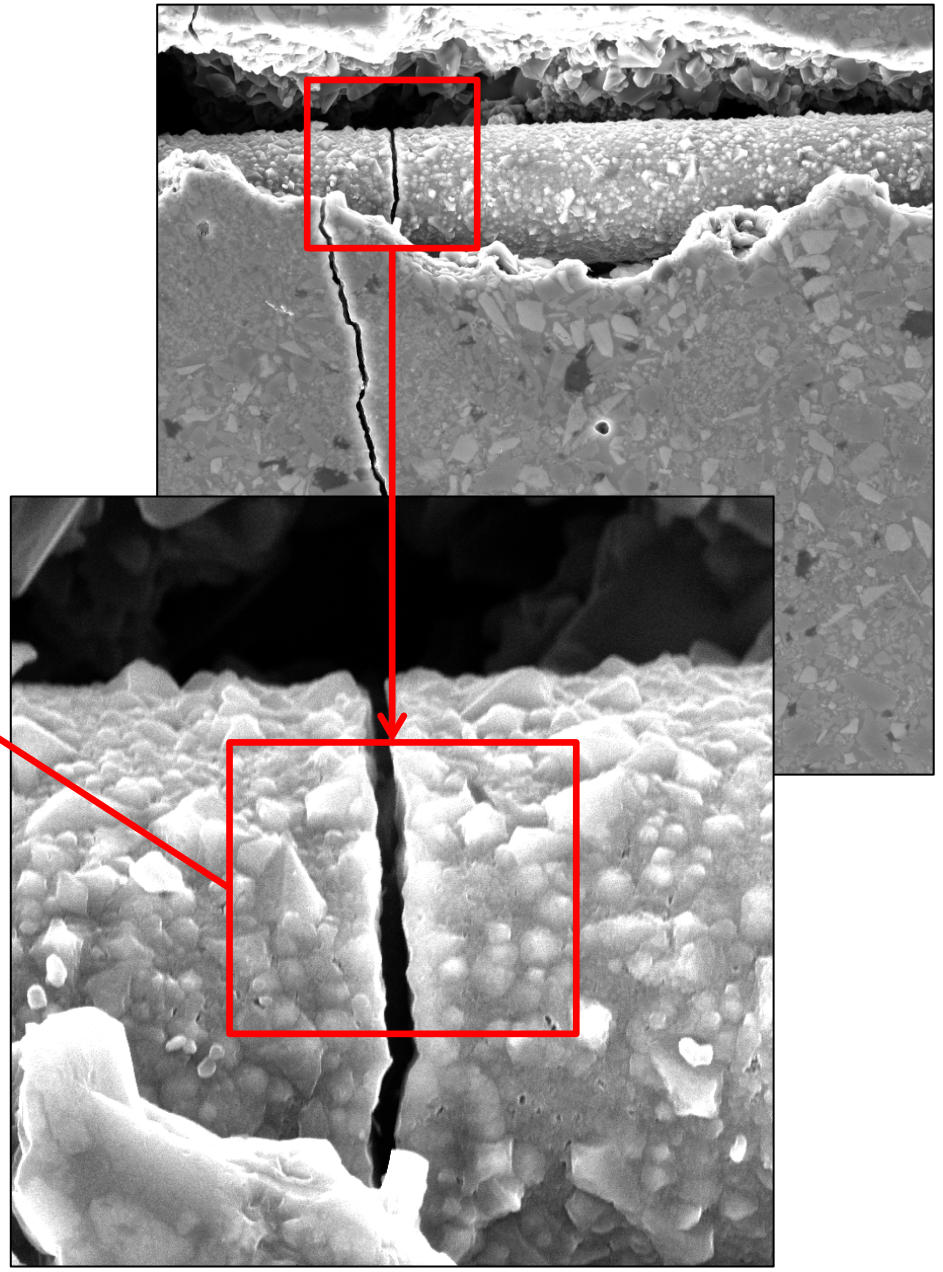
Questions

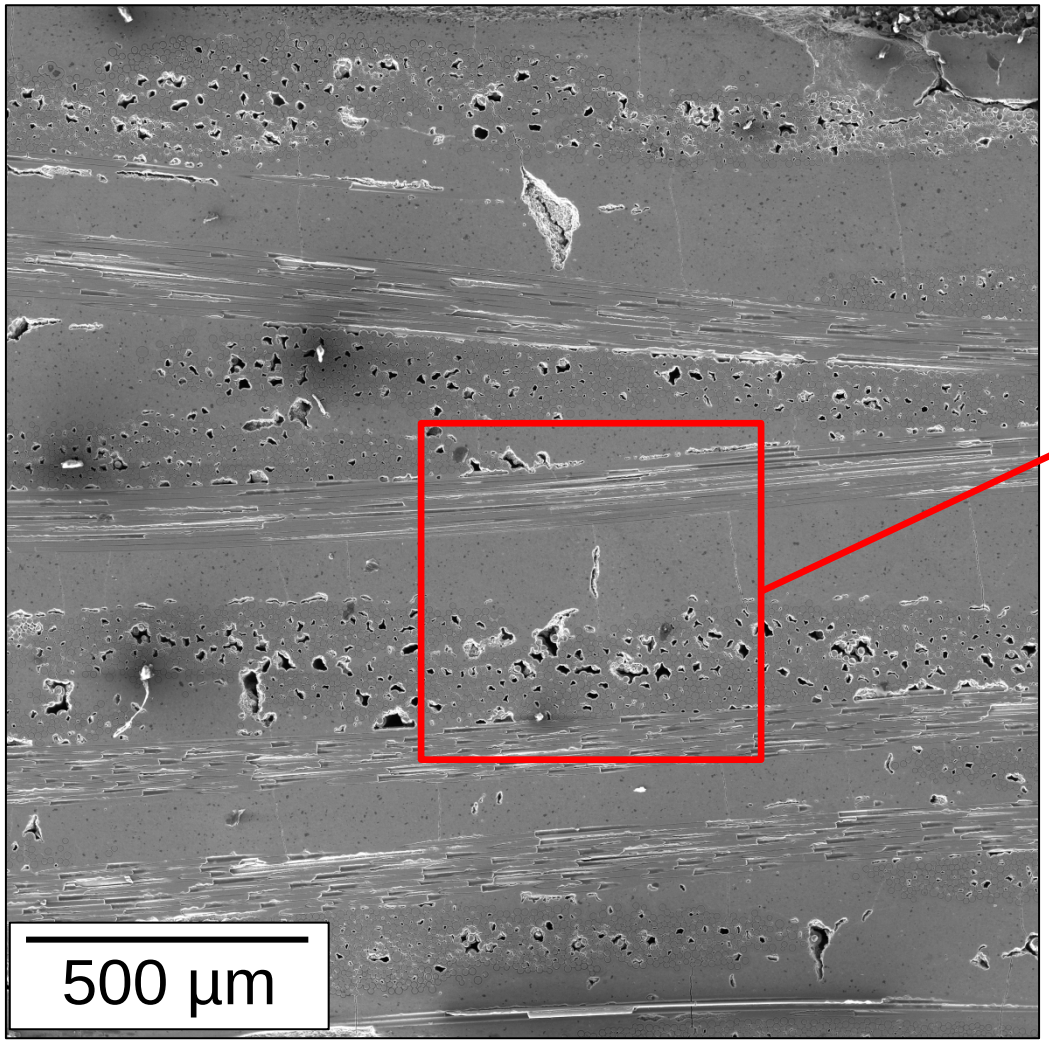
- What causes the apparent gap in COD measurements?
- Does COD change with repeated loading?
- How do cracks evolve with load and propagate through the microstructure?

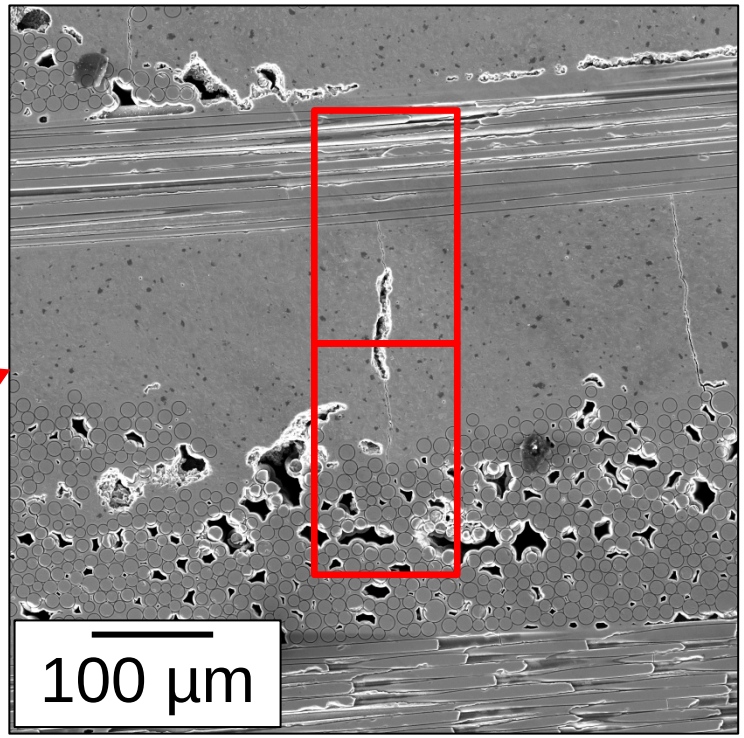
Sample 2 – Sample Larger Area, More Cracks





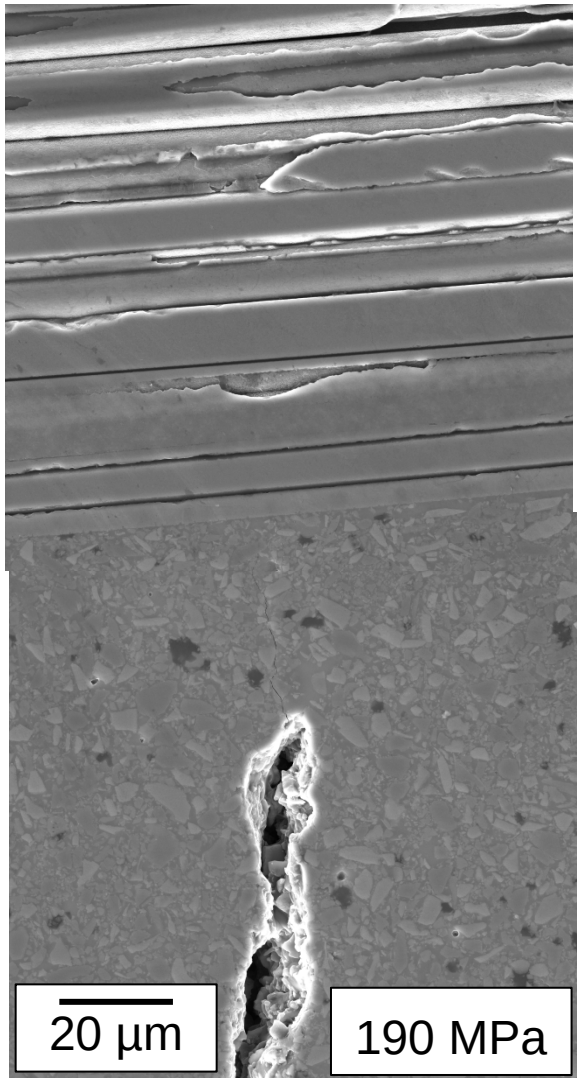


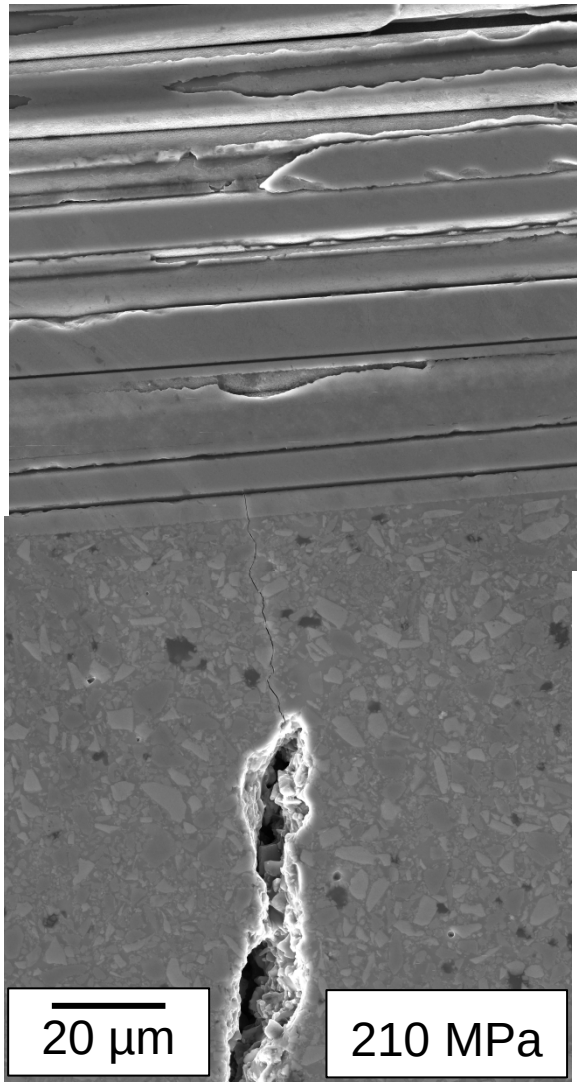


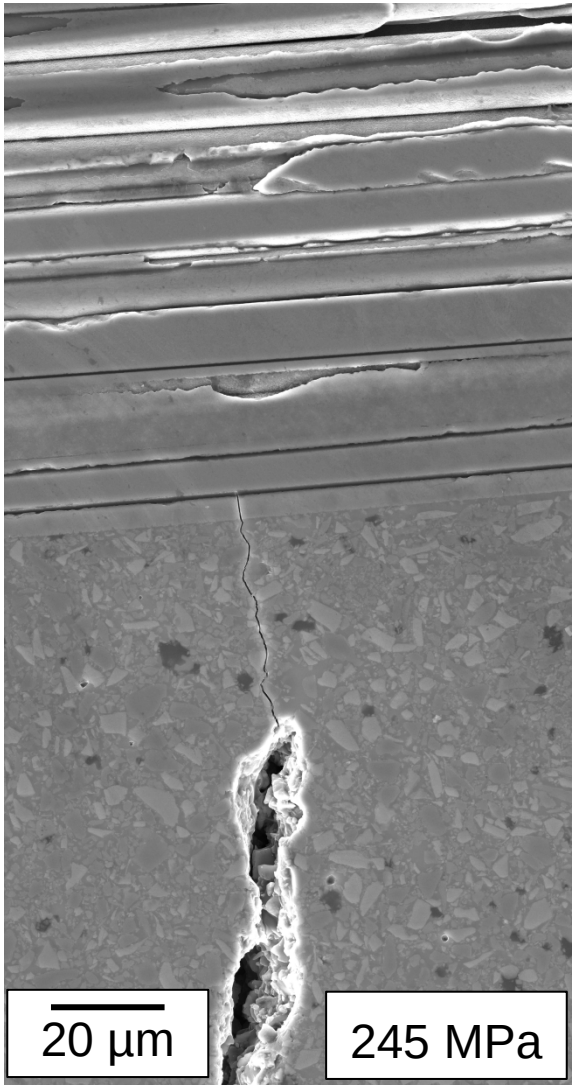


- Observations and measurements include cracking through both transverse and longitudinal tows, as well as matrix rich regions
- Some cracks grow from pores

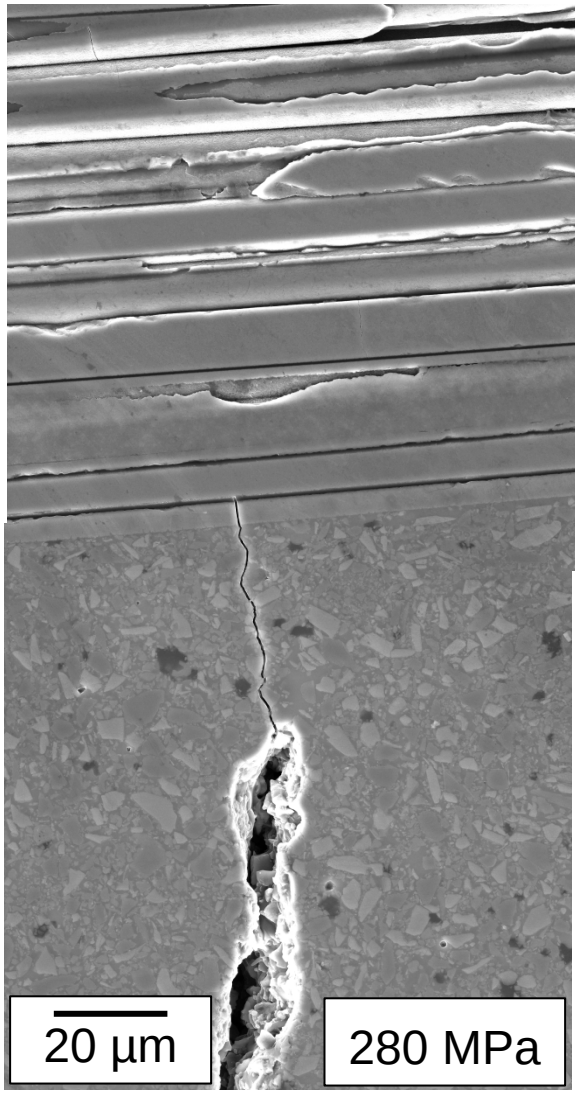
Crack growing into a longitudinal tow

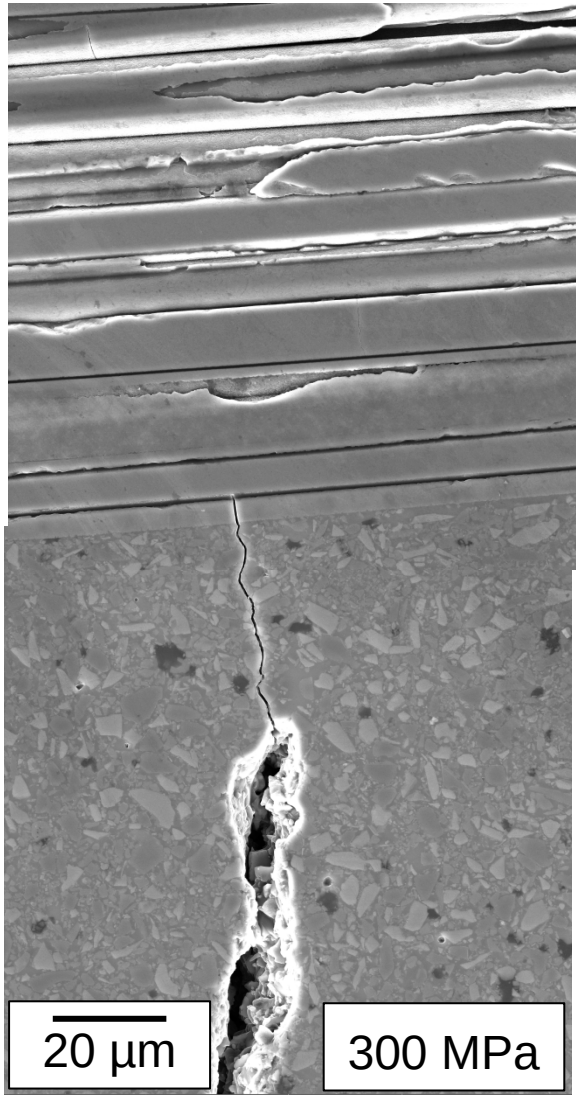




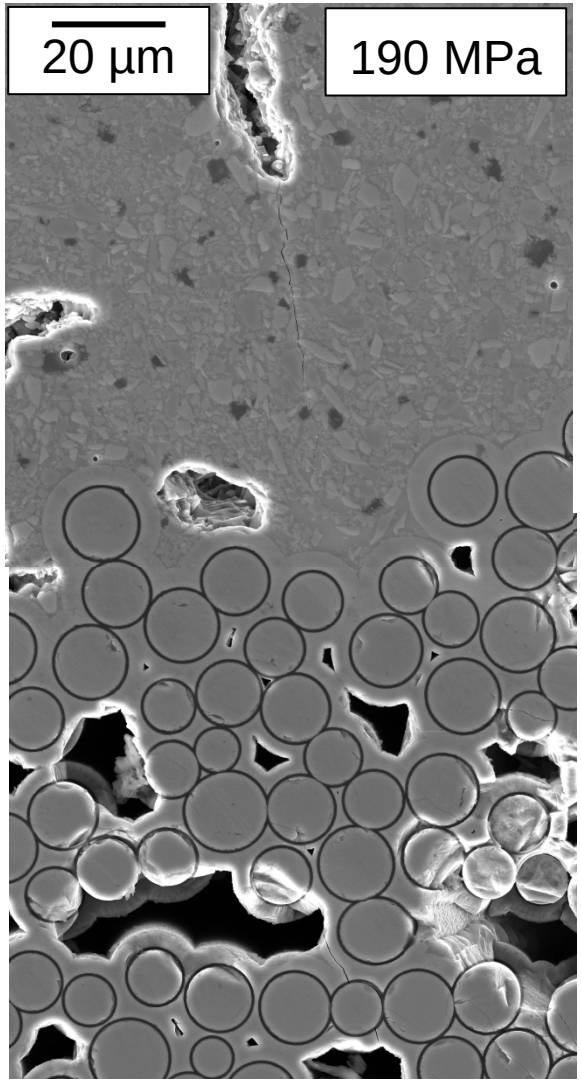


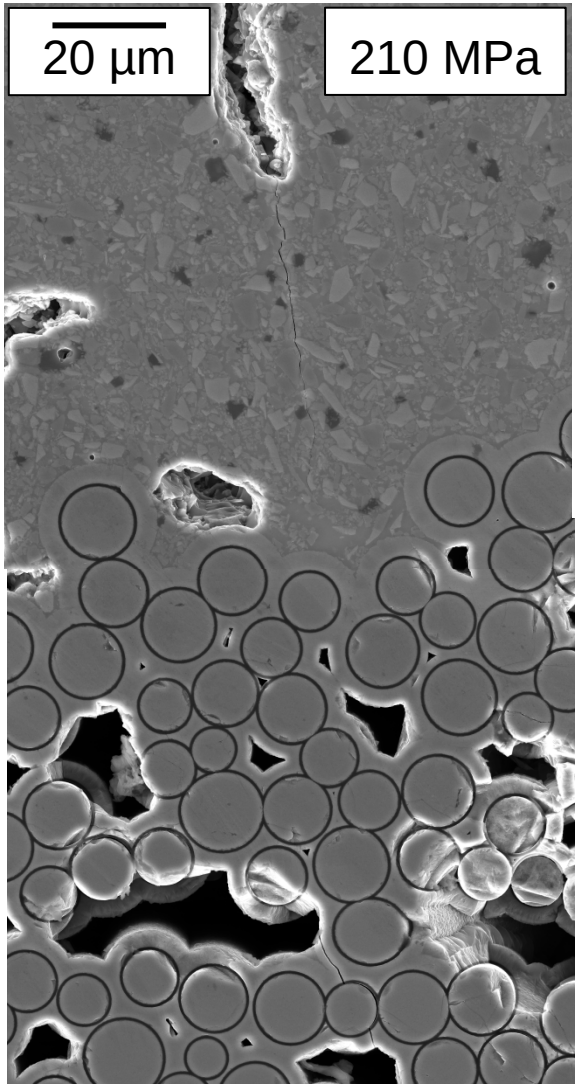
Crack growing into a longitudinal tow

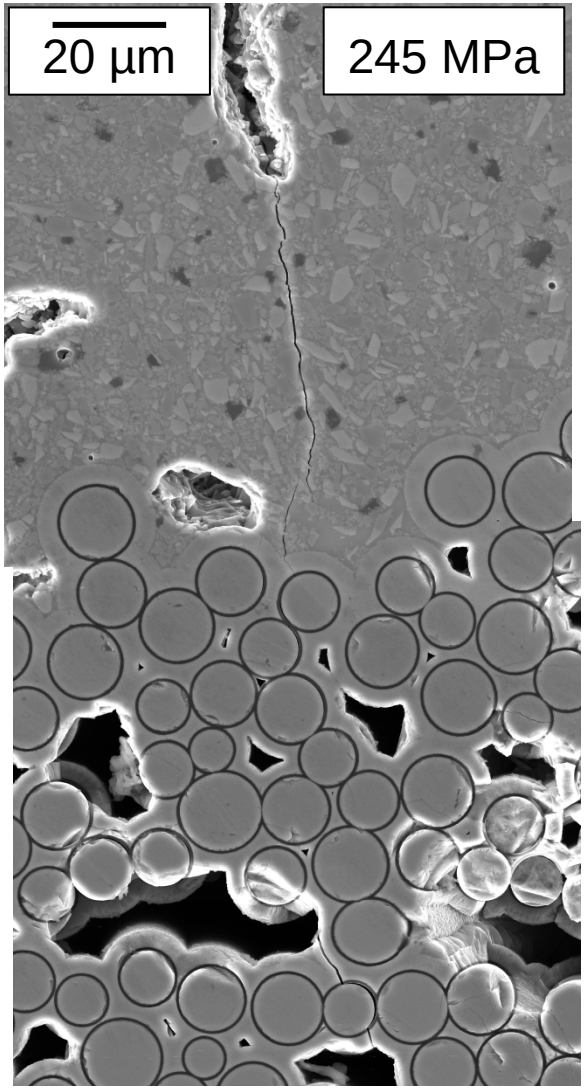




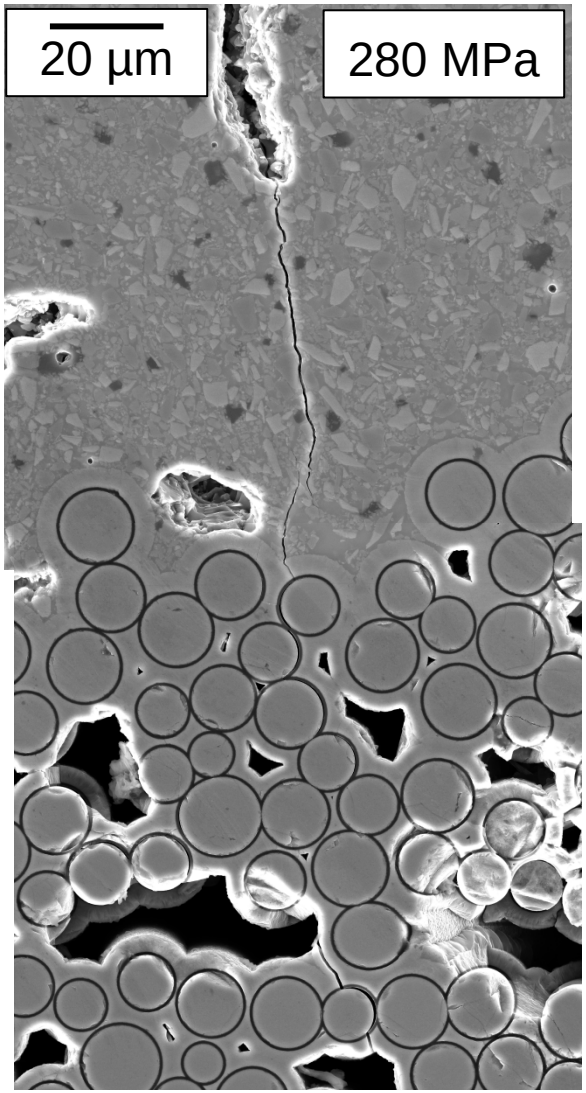
Crack growing into a transverse tow

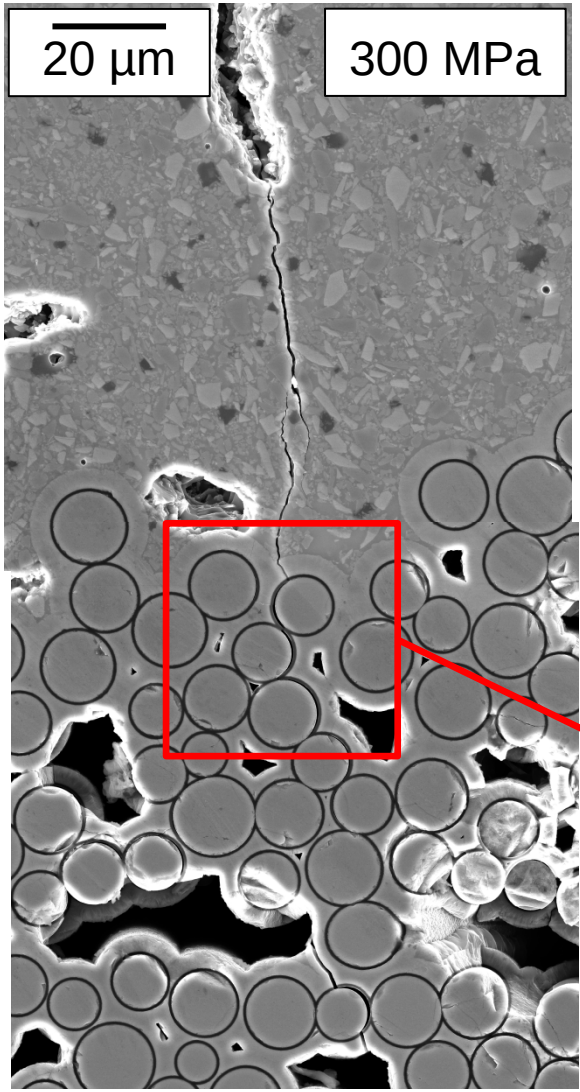




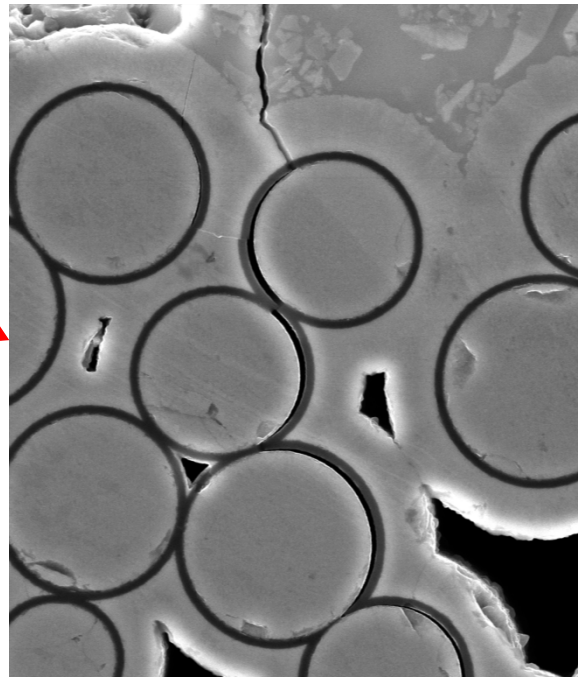


Crack growing into a transverse tow

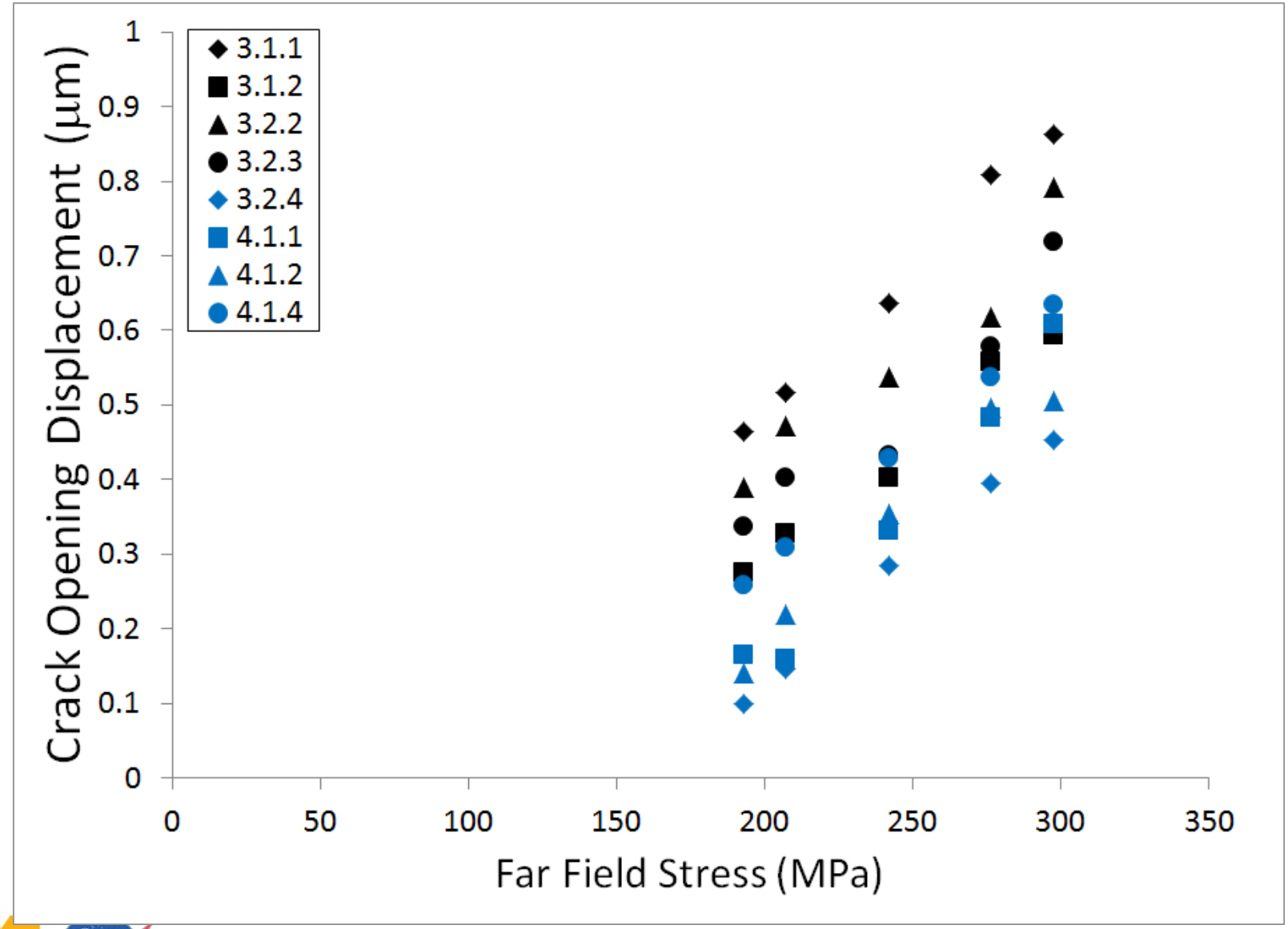




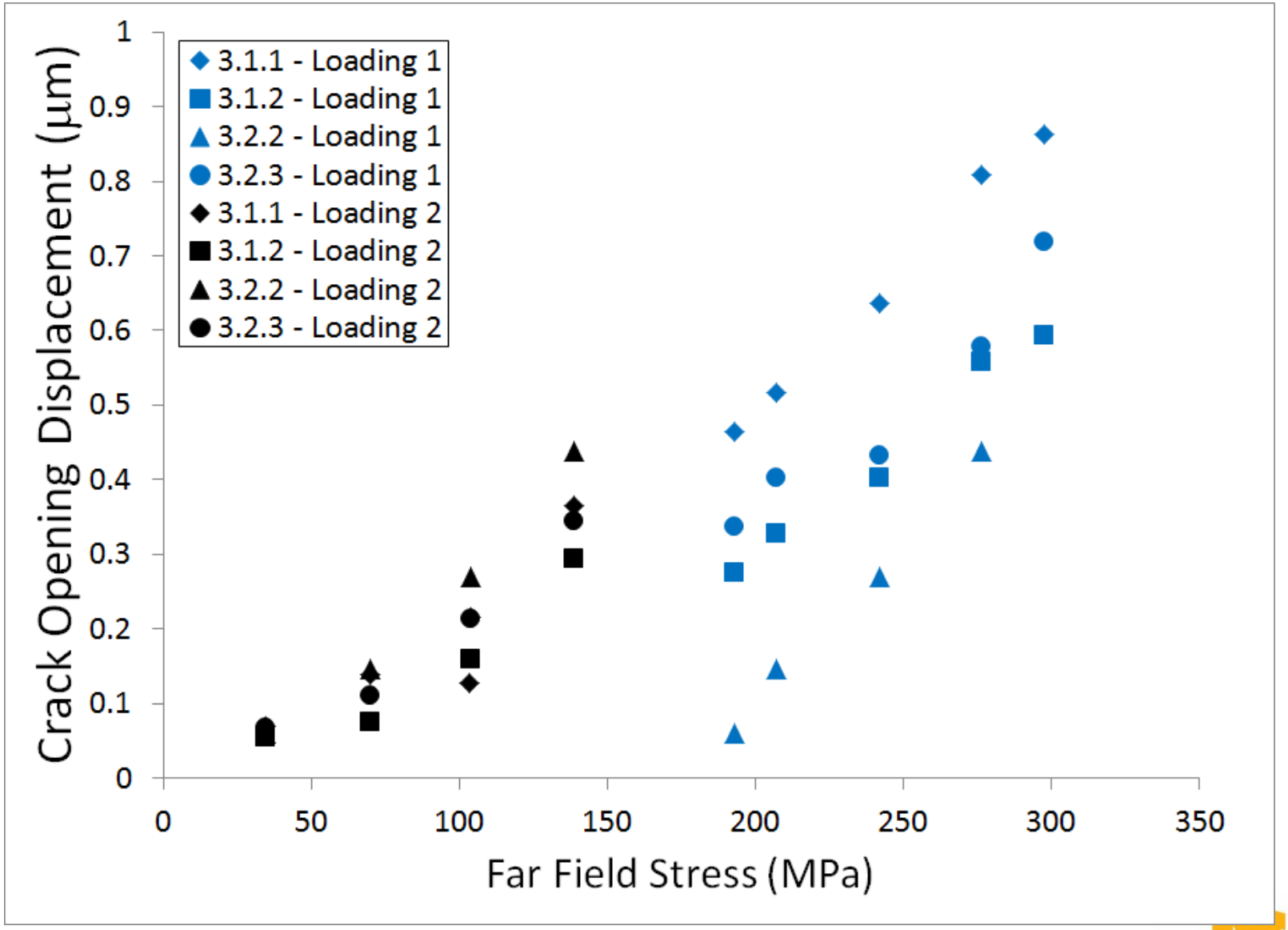
- From high load images, we can see the crack path and we can then go back to lower load images to see when the crack grew through these areas



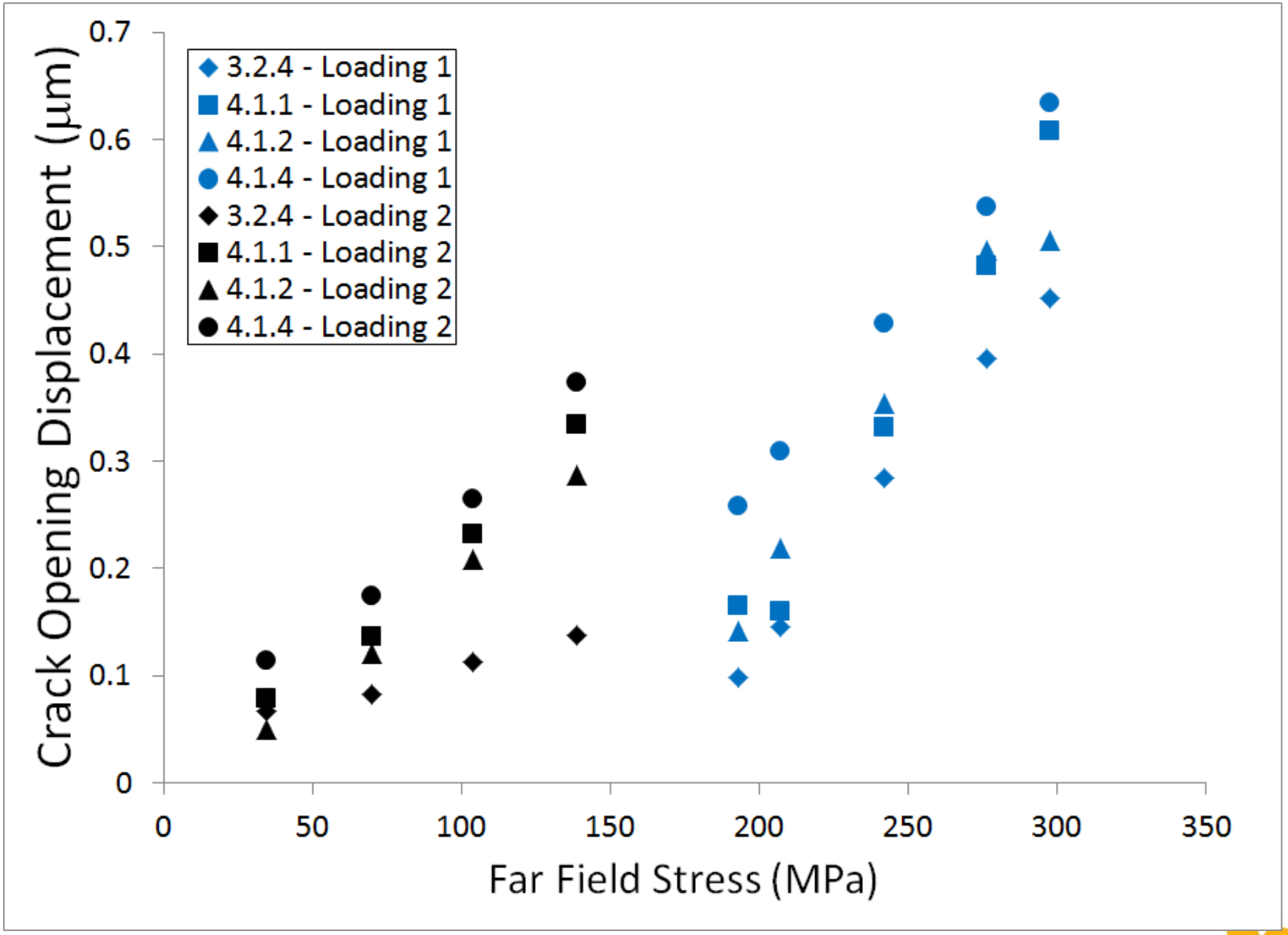
Loading 1 - COD Variation Similar to Sample 1



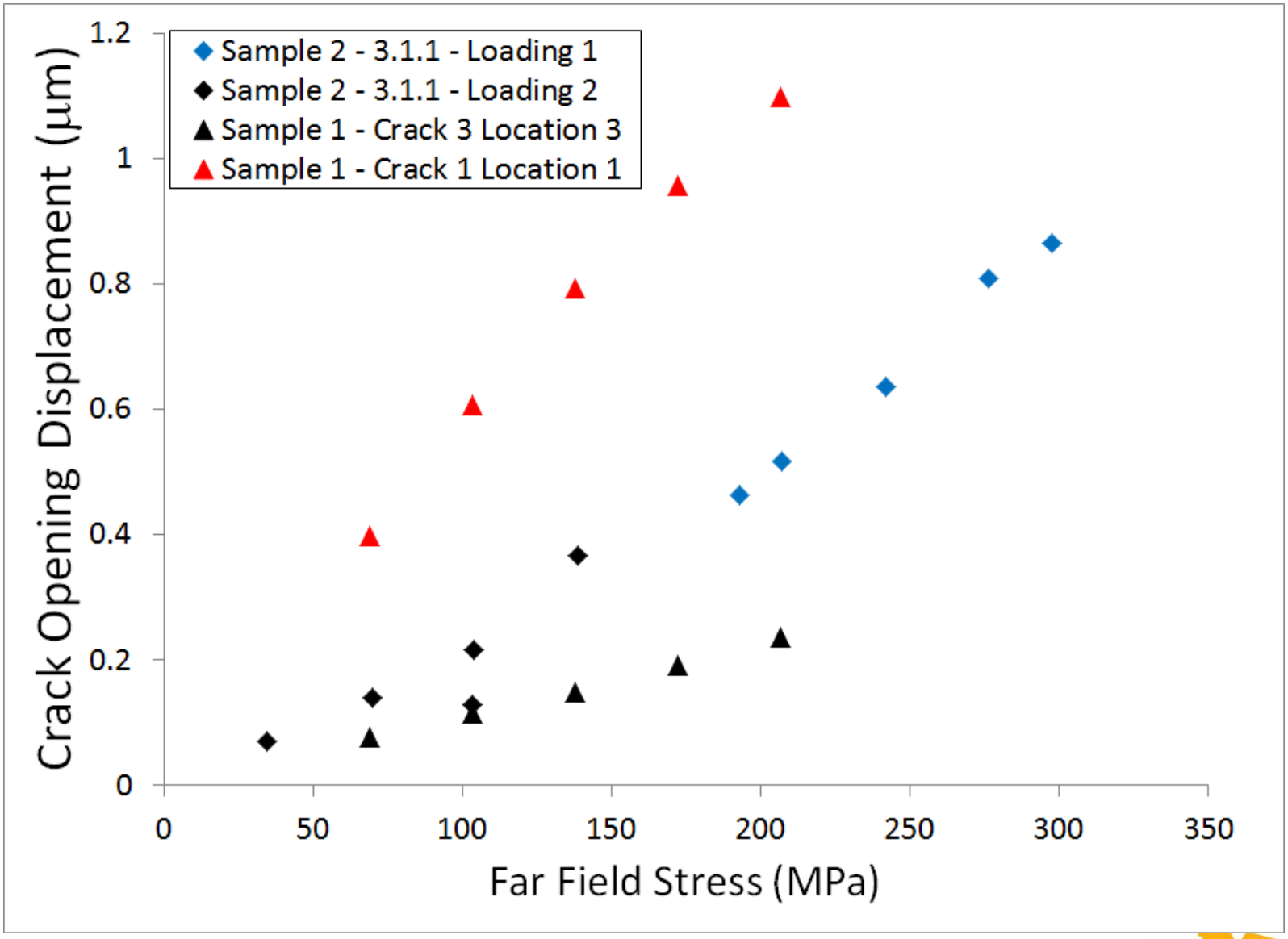
Loading 2 - Less Variability, Larger COD



Loading 2 - Less Variability, Larger COD



Compare COD Variation Between Samples



Summary and Future Work

Summary

- COD measurements from sample 2 are consistent with measurements from sample 1
- COD is affected by repeated loading
- Initial gap in COD data for sample 1 due to sampling few cracks and small crack lengths

Future Work

- Quantify COD variation along given crack in Sample 2
  - Sample 1 measurements: 1 μm increments, average taken over 10 μm
  - Sample 2 measurements: 10 μm increments, average taken over 100 μm
- Quantify crack interactions with microstructure
- Repeated cycling with opening at higher loads to determine effect of cycling on COD